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## Service-Based Socio-Cyberphysical Network Modeling for Guided Self-Organization

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### Abstract

Socio-cyberphysical networks tightly integrate humans, real-world objects and IT infrastructure. In some cases of cyberphysical networks, their configuration can be done in a centralized way (e.g., automated production line configuration). However, for socio-cyberphysical networks the centralized control is not possible due to the independence and autonomy of the network members (e.g., employees of an enterprise). The paper proposes an approach to model such network via a set of interacting socio-inspired services. Such services are capable to model behavior of the network participants taking into account their preferences, strategies and social norms. The interoperability of the services is achieved due to the usage of common standards (such as WSDL and SOAP) at the technological level, and common ontology at the semantic level. The developed conceptual model of socio-inspired service is presented together with behavior patterns and methods for their processing.

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**Keywords:** socio-cyberphysical system; socio-inspired service; service-based modeling; behavior modeling; behavior pattern

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### 1. Introduction

Cyberphysical networks tightly integrate heterogeneous resources of the physical world and IT world<sup>1,2</sup>. This term is tightly related to such terms as Web 4.0<sup>3,4</sup> and Internet of Things<sup>5,6,7</sup>. Currently, there is a significant amount

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of research efforts in the area of cyberphysical networks and their applications, e.g., in transportation<sup>8</sup>, production<sup>9</sup>, and many other. Having analysed the state-of-the-art of different CPS approaches and supporting technologies, among the other conclusions, Horvath and Gerritsen conclude that “the next-generation of CPSs will not emerge by aggregating many un-coordinated ideas and technologies in an incremental fashion. Instead, they will require a more organized and coordinated attack on the synergy problem, driven by an overarching view of what the future outcome should be”<sup>10</sup>.

Configuration of cyberphysical networks is a complex task, which is currently researched intensively<sup>11,12,13</sup>. In many cases such systems can be controlled in a centralized way; and given efficient configuration algorithms, nearly optimal configurations can be achieved. The situation changes when dealing with socio-cyberphysical networks. Such networks go significantly beyond the ideas of the current progress in cyber-physical systems, socio-technical systems and cyber-social systems to support computing for human experience<sup>14</sup>. They tightly integrate physical, cyber, and social worlds based on interactions between these worlds in real time. Such systems rely on communication, computation and control infrastructures commonly consisting of several levels for the three worlds with various resources<sup>15</sup> as sensors, actuators, computational resources, services, humans, etc. Socio-cyberphysical networks belong to the class of variable systems with dynamic structures. Their resources are too numerous, mobile with a changeable composition. Planned resource interactions in such systems are just impossible. Obviously, one cannot control all members of such a network, but only some of its components (e.g., machines, computers, intelligent devices, etc.) to influence the whole network operation. Guided self-organization of socio-cyberphysical networks could be an efficient way to organize its behavior. However, taking into account not only combination of information from sensors and information systems but also application of behavior analysis techniques for predicting future actions of human network members could significantly improve the efficiency of such an organization.

One of the ways to do it is to model the operation of such a network. The paper proposes an approach to model a socio-cyberphysical network via a set of interacting socio-inspired services. Such services are capable to model behavior of the network participants taking into account their preferences, strategies and social norms of the network members. The interoperability of the services is achieved due to the usage of common standards (such as WSDL and SOAP) at the technological level, and common ontology at the semantic level. Different types of services and their behavior models are described as well as different negotiation strategies.

The paper is structured as follows. The description of the developed modelling approach to guided self-organization is discussed in the next section. Section 3 presents the conceptual model of socio-inspired service lying in the core of the proposed approach. Behavior analysis techniques are discussed in section 4. Main results are summarized in the conclusion.

## 2. Guided Network Self-Organization: Approach

The analysis of literature related to organizational behavior & team management has showed that the most efficient teams are self-organizing teams working in the organizational context (Fig. 1). For example, social self-organization has been researched in a number of efforts<sup>16,17</sup>. However, in this case there is a significant risk for the group to choose a wrong strategy preventing from achieving desired goals. For this purpose, self-organizing groups / systems need to have a certain guiding control from an upper level. However, In order for distributed systems to operate efficiently, they have to be provided with self-organization mechanisms and negotiation protocols.

The process of self-organization of a network assumes creating and maintaining a logical network structure on top of a dynamically changing physical network topology. This logical network structure is used as a scalable infrastructure by various functional entities like address management, routing, service registry, media delivery, etc. The autonomous and dynamic structuring of components, context information and resources is the essential work of self-organization<sup>19</sup>. The network is self-organized in the sense that it autonomously monitors available context in the network, provides the required context and any other necessary network service support to the requested services, and self-adapts when context changes. Self-organizing systems are characterized by their capacity to spontaneously (without external control) produce a new organization in case of environmental changes. These systems are particularly robust, because they adapt to these changes, and are able to ensure their own survivability<sup>20</sup>.

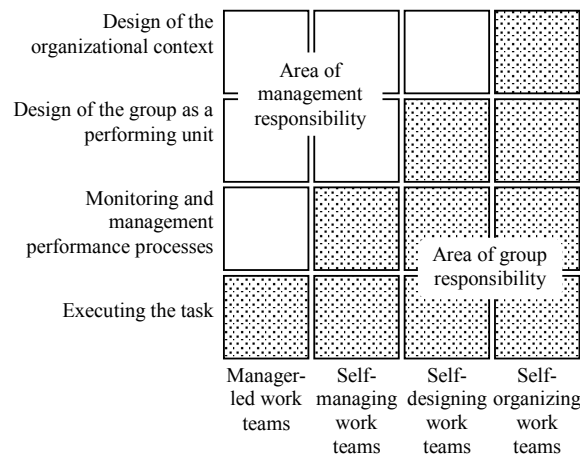


Fig. 1. Authority of work group types<sup>18</sup> (adapted).

The guided self-organization has got some significant attention in the scientific community<sup>21,22</sup>. An approach has been developed by the authors<sup>23</sup> that enables a more efficient self-organization based on the “top-to-bottom” configuration principle, which assumes conceptual configuration followed by parametric configuration, which is the basis of the presented modelling approach. In this approach, the guiding control via policy transfer from an upper level is used to guide self-organizing groups.

The proposed approach models a socio-cyberphysical network via a set of interacting socio-inspired services. The approach is based on the following principles: self-management and responsibility of the services, decentralization, and integration of policy transfer (guiding control via policy transfer) with network organization (without any social hierarchy of command and control within a level), guiding control from the upper level and co-operation between services. The idea can be interpreted as producing “guided order from noise”. Such system falls into the class of purposeful systems<sup>24</sup>.

Self-organization of services is considered as a threefold process of (i) cognition (where subjective context-dependent knowledge is produced), (ii) communication (where system-specific objectification or subjectification of knowledge takes place), and (iii) synergetical co-operation (where objectified, emergent knowledge is produced). The Individually acquired context-dependent (subjective) knowledge is put to use efficiently by entering a social co-ordination and co-operation process. The objective knowledge is stored in structures and enables time-space distancing of social relationships.

In order to achieve the realism and dynamics of the self-organizing system, its components (services) have to be creative, knowledgeable, active, and social. The services that are parts of a system permanently change their joint environment what results in a synergetic collaboration and leads to achieving a certain level of collective intelligence. This is also supported by the fact that individual service behavior is partially determined by the social environment the services are contributing to (called “norms”). For this purpose a protocol has been developed based on the BarterCast approach<sup>25</sup> that originates from the idea of building a network by a service representing all interactions it knows about.

The overall scheme of the approach is shown in Fig. 2. The lower part of the figure represents the modelled socio-cyberphysical network and the model itself in the form of service network. The upper part represents the socio-inspired service modelling a member of the socio-cyberphysical network. The detailed description of the service is given in the next section. The interoperability at the technological level is provided via usage of common standards and protocols, the interoperability at the level of semantics is provided via usage of common semantics and terminology described via ontologies<sup>26,27</sup>.

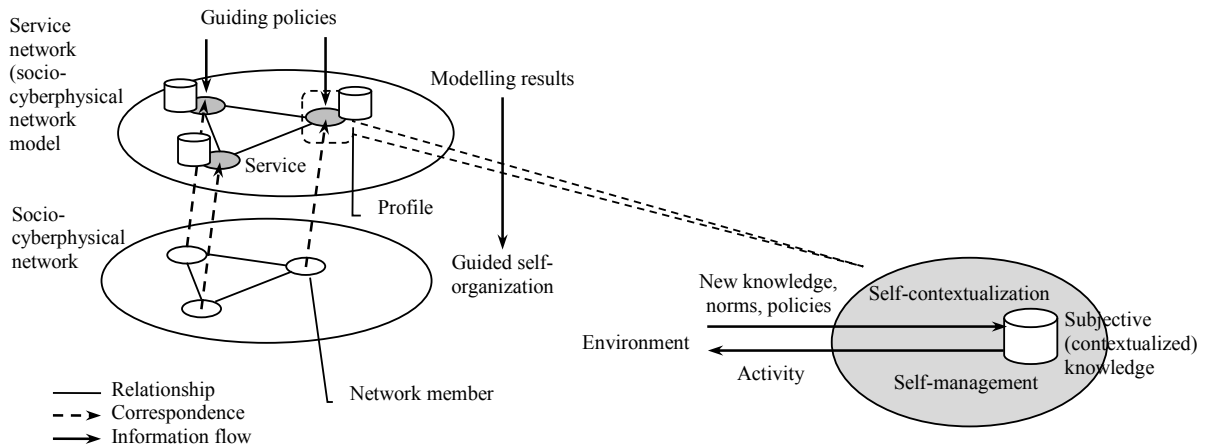


Fig. 2. Modelling approach overview.

### 3. Conceptual Model of the Socio-Inspired Service

Fig. 3 represents the developed conceptual model of the socio-inspired service. Its main components are described below.

**Service** is an acting unit of the self-configuration modelling process. It can represent a sensor, electronic device, human, etc. The service has **structural knowledge**, **parametric knowledge**, and **profile**. It is characterized by such properties as self-contextualization, autonomy, and proactiveness and performs some **activities in the community**.

**Structural Knowledge** is a conceptual description of problems to be solved by the **service**, its internal ontology. It describes the structure of the service's **parametric knowledge** and the terminology of its **context** and **profile**.

**Parametric knowledge** is the knowledge about the actual situation. Its structure is described by the service's **internal ontology**, and the parametric content depends on the **context** of the current situation. It defines the service's **behavior**.

**Context** is any information that can be used to characterize the situation of the service<sup>28</sup>. The context is purposed to represent only relevant information and knowledge from the large amount of those. Relevance of information and knowledge is evaluated on a basis how they are related to a modelling of an ad hoc problem. The context is represented in terms of the service's **internal ontology**. It is updated depending on the information from the service's **environment** and as a result of its **activity in the community**. The context updates the service's **parametric knowledge**, which in turn defines the service's behavior. The ability of a system (service) to describe, use and adapt its behavior to its context is referred to as **self-contextualization**<sup>29</sup>. The presented approach exploits the idea of self-contextualization to autonomously adapt behaviors of multiple services to the context of the current situation in order to model behavior changes according to this context. For this reason, the presented conceptual model enables context-awareness and context-adaptability of the service.

**Environment** is the surroundings of the socio-cyberphysical network, the member of which is modelled by the service, that may interact with the network members. The environment affects the service's **context**. The service can affect the environment if it has appropriate **functionality** (e.g., a manipulator can change the location of a corresponding part).

**Functionality** is a set of cyber-physical functions the service can model. Via the functionality the service can modify its **environment**. The functionality is described by the service's **profile**.

**Profile** describes the service's **functionality, preferences and strategies** in terms of its **internal ontology**.

**Behavior** is the service's capability to perform certain actions (**activity in community**) in order to change the own state and the state of the environment from the current to the preferred ones. The behavior is defined by the service's **preferences** and **strategies**, as well as by the guiding **policies** defined on a higher level.

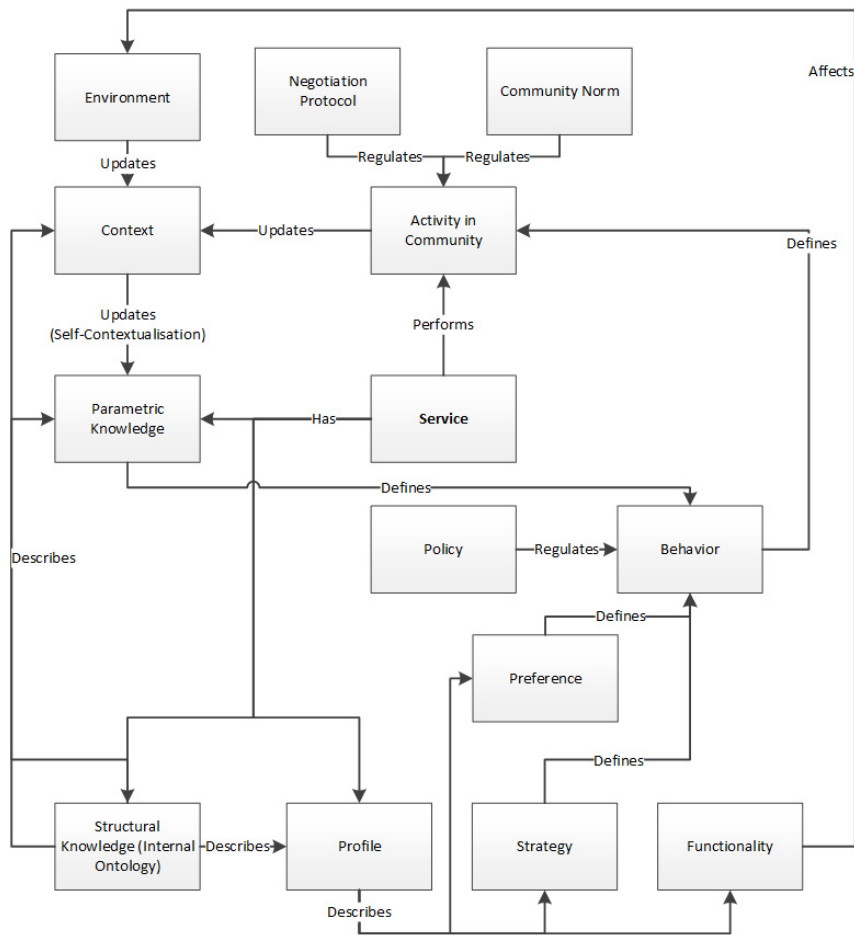


Fig. 3. Socio-inspired service: conceptual model.

**Policy** is a set of principles and/or rules coming from a higher level to guide **behavior** and achieve rational outcomes on the level of self-configuration.

**Preference** is a service's attitude towards a set of own and/or environmental states and/or against other states. The preferences are described by the service's **profile** and affect its **behavior**.

**Strategy** is a pre-defined plan of actions rules of action selection to change the service's own state and the state of the **environment** from the current to the preferred ones. The strategy is described by the service's **profile** defines the service's **behavior**.

**Activity in community** is a capability of the service to communicate with other services and negotiate with them through the service's **behavior**. It is regulated by the **negotiation protocol** and **community norms**.

**Negotiation protocol** is a set of basic rules so that when services follow them, the system behaves as it supposed to. It defines the **activity in community** of the services.

**Community Norm** is a law that governs the service's **activity in community**. Unlike the negotiation protocol, the community norms have certain degree of necessity ("it would be nice to follow a certain norm").

#### 4. Behavior Analysis

The developed modelling approach assumes description of functionality, preferences and strategies of the socio-cyberphysical network members via updatable and extendable profiles. Usage of the profiles makes it possible to “individualize” the behavior of services modelling different human members. For this reason methods of human preferences revealing have been developed.

The preferences are revealed via the analysis of the situations the network member faces most often, parameters of objects and actions most often occurring or avoiding in the decisions (actions) made by the network member, optimization criteria the network member most often follows or not. One of the main features of the developed profile model is presence of the information related to antecedents and consequences of the made decisions and undertaken actions what makes it possible to perform the functional analysis of the human behavior.

The functional behavior analysis is one of the behavior analysis techniques considering frequency of key behavior events related to certain human activity<sup>30</sup>. It is also known as ABC analysis (antecedent, behavior, consequence) and is based on identification of both antecedents and consequences of the behavior. As a result, it is possible to build a conditional behavior model, which would let one know (to predict) how a human would act in a given situation.

The result of such an analysis produces typical decisions (actions) made by the considered person in certain situations (behavior patterns). Example of behavior pattern is presented below:

- **Context:** there are two orders in the queue to be processed.
- **Antecedent:** a complicated order arrives, which requires additional attention.
- **Possible behavior:** process the orders in the queue first; process the complicated order first.
- **Preferred behavior:** process the complicated order first.
- **Consequence:** the complicated order has been processed quickly; the orders in the queue have been delayed.

The behavior pattern revealing techniques used in the proposed approach include:

1. Revealing human behavior patterns for problems with the same structure but different parameters. In this case, the structural knowledge constituent will be the same, and the parametric knowledge constituent will be different.
2. Revealing human behavior patterns for different problems solved by the same person. This technique assumes analysis of structures of different problems trying to find similarities associated with the same decisions / actions.
3. Revealing human behavior patterns based on the optimization criteria (problem parameters with highest or lowest values) the person tends to follow or avoid (e.g., the driver prefers moves faster or with less maneuvers). Aggregated (e.g., weighted average) criteria can also be analyzed.
4. The above techniques applied not to one person but to different persons with similar profiles. This technique utilizes collaborative filtering mechanisms<sup>31</sup>.

To implement the first three techniques the following methods have been developed:

1. Decision / action clustering method. The decisions made by the person and actions undertaken are grouped into clusters. Based on the clusters built the common properties (parameters) of the problems and decisions / actions grouped into one cluster are identified. The results of this method can be refined if there is enough historical data accumulated and clustering can be done taking into account the context of the situation when corresponding decisions have been made (including and preferences of the person at the moment of decision making as well as information about behavior antecedents and consequences).
2. The alternative analysis method. Unlike the previous method searching for similar person's decisions, this method is aimed at the analysis of differences between decisions made by the person and actions undertaken. Based on the analysis of the identified differences taking into account the situation context (as well as preferences of the person and information about behavior antecedents and consequences) namely definition of the main generic differences of the made decisions, the behavior patterns are revealed.

To implement the fourth technique of human behavior pattern revealing, a method based on the collaborative filtering mechanisms used for building collaborative recommendation systems. This technique would enable to

predict human behavior even in situations, in which this person has never got. For this reason, the decisions made by persons with similar properties are used.

Application of the above techniques would enable to build services with realistic behavior modelling real people (e.g., via usage of opportunistic planning<sup>32</sup> mechanisms). As a result of such modelling, the most suitable policies can be identified to guide the self-configuration process of socio-cyberphysical networks.

## 5. Conclusion

The paper addresses the problem of socio-cyberphysical network modelling via usage of socio-inspired services. In such networks, the centralized control is not usually possible. As a result, there is a need in techniques to provide efficient guided self-organization. The proposed approach is based on the idea of the network modelling for the analysis of possible guiding influences and selection of the most efficient ones. One of the major problems here is that such modelling has to include modelling of human behavior. This is addressed via application of socio-inspired services, acting on the basis of social norms and preferences. The realism of such modelling is achieved via application of behavior patterns revealed for the socio-cyberphysical network members.

By the moment a technological framework and supporting techniques have been developed. The techniques have already proved themselves in other areas (for example, such as recommendation systems), however, the accumulation of historical behaviour data and testing the approach in real-world applications is the goal of future work.

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